GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT INITIATION

Date 2-11-64

Project Title: Studies of the Seismicity of the State of Georgia, Phases I and II

Project No.: A-754

Project Director: John E. Husted

Sponsor: U. S. Department of Commerce, Coast and Geodetic Survey

Effective: 1-1-64 Estimated to run until: 12-31-65

Type agreement: Contract No. CCS-1237(Neg)

Amount: $39,955.00

Reports: To be determined

Contact Person: Dr. Sylvester T. Algermissen, Chief
Data Analysis Branch
Seismology Division
Office of Physical Sciences
Coast and Geodetic Survey
Washington 25, D. C.

Add. has been changed

Assigned to Chemical Sciences and Materials Division

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GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT TERMINATION

Date May 3, 1967

PROJECT TITLE: Studies of the Seismicity of the State of Georgia, Phases I and II

PROJECT NO: A-754

PROJECT DIRECTOR: J. E. Husted

SPONSOR: U. S. Department of Commerce, Coast and Geodetic Survey

TERMINATION EFFECTIVE: May 3, 1967

CHARGES SHOULD CLEAR ACCOUNTING BY: All charges have cleared

REPORTS
300.A-754

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March 11, 1964

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Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington 25, D. C.

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch, Seismology Division

Subject: Letter Report No. 1, Project A-754
"Studies of the Seismicity of the State of Georgia
Phases I and II" - Contract No. CGS-1237(Neg)
Covering the Period from January 1 to March 1, 1964

Gentlemen:

This report has been delayed on several counts, including about a week's illness on my part and travel.

Our work to date has included the two weeks in Washington (January 27-February 7) for Mr. Lafayette Maynard for instructional purposes. Since his return Mr. Maynard has been devoting his time to the study of the records with the application of knowledge gained in Washington. In addition to the above, Mr. Maynard has found it necessary to adjust our equipment according to the information learned while in Washington in order that we may obtain the precision information required.

Mr. Dorman and I have spent a major part of our time investigating equipment to be used for the recording of the local event timing. As of March 5, we sent purchase requests for a Texas Instruments oscillo-riter and a Specific Products WWV receiver. These pieces of equipment should be in by the latter part of April.

It also should be mentioned that we have purchased or have on order Jeffries' travel-time tables, Bullen's An Introduction to the Theory of Seismology and Gutenberg's and Richter's Seismicity of the Earth. Our library has or is obtaining all the other books of the bibliography given Mr. Maynard. We are exploring costs and manufacturing details on maps, globes, and charts with particular reference to a globe between 24" and 32" in diameter.

Our plans are to systematize all events that we can recognize with a series of data sheets for each event which we may later check against the data release sheets of the USC&G and blast schedules. We have obtained quarry location maps from all the surrounding states in order to facilitate the determination of source of obvious blasts. Our plans for the next several months will be along the lines of developing accurate data recording and filing in

order that we may check the exact arrival times against records of USC&GS. We will begin to plot on polar and cartesian graph paper the various teleseismic and local events which we can identify. As soon as we have sufficient PDE data to correlate, we will prepare travel-time charts for the Atlanta station.

One of the goals of the project is determination of the directional characteristics of the station. This will be done by comparing the distances, azimuths, and magnitudes of teleseismic events which we detect, with the distances, azimuths, and magnitudes of events which we do not detect. In order to ease the burden of those calculations, a computer program has been written to calculate the distance and azimuth from the ATL Observatory to any other point on the earth's surface. The program is written in a representation of ALGOL and is run on the Burroughs 220 at the Computer Center on campus. A request is being made to USC&GS, Washington, for epicenter data in IBM card or paper tape form in order to eliminate, if possible, the step of card punching.

We are planning to start work with quarries either in May or June for recording of the local event data. All the quarries to date have been most cooperative.

Incidentally, we have heard from Dr. Fred E. Followill on the Alabama earthquake of 18 February 1964. We intend to cooperate with all of these individuals here in the Southeast and plan to correspond with both Oxford and Blacksburg. We intend to visit the McMinnville station some time before the end of the month, if possible. Our teletype number is Area Code 404, 5272308, if this would be useful to you.

We look forward to seeing you when you visit with us and in order to facilitate matters, let me give you the following dates of school interest:

Examinations for Winter Quarter - March 16-20

Registration for Spring Quarter - March 30

We in the Engineering Experiment Station work a 40-hour week irrespective of the between quarter time out for the academic side, but it does to some extent affect the freedome of some students who work with us.

Respectfully submitted.

John E. Husted, Head
Minerals Engineering Group
Project Director

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Copies: (4) to Addressee
BCC: (1) to Dr. Frederick Bellinger
BCC: (2) to Security Office
(2) to File.

May 4, 1964

Area Code: 404
Telephone: TR. 6-5976

Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington 25, D. C.

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch, Seismology Division

Subject: Phase Letter Progress Report No. 2, Project A-754
"Studies of the Seismicity of the State of Georgia,
Phases I and II" - Contract No. CGS-1237(Neg)
Covering the Period from April 1 to May 1, 1964

Gentlemen:

The progress on our project, the calibration of the seismic station, has progressed as stated in our Quarterly Progress Report No. 1, except we have not received the equipment ordered in March. It is anticipated that it will arrive early in May.

Mr. Maynard and I attended the American Geophysical Union's annual meeting held in Washington April 20-24. I regret that I was unable to see you at the appointed time but when the Senate calls, there is no alternative.

While in Washington, we contacted through the agency of Jim Jordan the United Dynamics people in Alexandria, and have arranged to be furnished paper tape punched with the PDE card data. In addition, we secured a copy of the memorandum in which instructions are to be found for a uniform punching of seismic data on computer cards. We will follow this method in the future for any cards that we punch.

Attached is a copy of a letter concerning a globe for approximately $600.00. We would like to inquire concerning whether or not unexpended capital funds left over from the timing and radio equipment (if any) could be used toward the purchase of such a globe.

Respectfully submitted,

John E. Husted, Head
Minerals Engineering Group
Project Director

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Copies: (4) to Addressee
(1) Enclosure

BCC: (1) to Dr. Bellinger
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A-754

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

April 9, 1964

Area Code: 404
Telephone: TR. 6-5976

Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington 25, D. C.

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch, Seismology Division

Subject: Quarterly Progress Report No. 1, Project A-754, Contractor, Georgia Tech Research Institute; Order No. 2020-4; Date of Contract - March 13, 1964; Amount of Contract: $39,955; Contract No. CGS-1237(Neg) (Sponsored by Advanced Research Projects Agency); Contract Expiration Date: 12-31-65; Project Scientist: John E. Husted, TR. 6-5976; Covering the Period from January 1 to April 1, 1964; Title of Work: "Studies of the Seismicity of the State of Georgia, Phases I and II."

Gentlemen:

A summary of activities performed during the above mentioned quarter is given below.

1. A computer program, written in a representation of ALGOL, for our Burroughs 220, has been put in operation using U. S. C. and G. S. seismic data cards for the determination of azimuths and distance for teleseismic events. Output data of the computer program are compared with the records from our seismographs to determine the events we have received - or not received and a record made, with the magnitude. As an example, we have determined, with a short period magnification of 50,000 and a "quiet" record, that a magnitude of 4.0 is at the ragged edge of recognition and interpretation for quakes off the south coast of Chiapas, Mexico.

2. A Texas Instruments oscillo-riter and a Specific Products WWV receiver are on order for timing local events. The local events program should be initiated before the next quarterly report. After calibration checks are made with close-by quarries, we plan to check blasts from one or both of two quarries near Gray, Georgia. Gray is near the epicenter of the March 12 "Macon, Georgia" earthquake. Blasts from this area should yield significant data. As an aside, the "Macon, Georgia" earthquake apparently falls near or on the intersection of two fault systems proposed by Georgia Tech personnel.

3. Mr. G. Lafayette Maynard, Research Assistant, of our staff spent two weeks at the end of January and beginning of February in the offices of U. S. C. and G. S., receiving training on recognition and interpretation of seismic events

as recorded on standard station seismographs. The volume of current teleseismic and local events recorded at Atlanta has kept him too busy to do much work on our older records.

4. Considerable publicity from the local press, T. V., and radio has resulted from the "Macon, Georgia" and Alaskan earthquakes.

FISCAL DATA

Contractor expenditures and commitments to date:

Expenditures January 1 - March 31, from Budget of $11,500.00 for Fiscal Year ending June 30, 1964:

Expended	$4,385.59
Encumbered	1,896.15
	$6,281.74

Free Balance: $5,218.26 for Fiscal Year ending June 30, 1964.

Technical Man-Year effort for three months of six months' budget period for January 1 - June 30, 1964 = 53.54 per cent.

Technical Man-Year effort for first quarter of two year contract = 11.74 per cent.

Estimated Funds to Complete Work: $33,673.26.

Respectfully submitted,

John E. Husted, Head
Minerals Engineering Group
Project Director

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Copies: (4) to Addressee
(6) to Director, Advanced Research Projects Agency,
Department of Defense

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

July 13, 1964

Area Code: 404
Telephone: TR. 6-5976

Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington Science Center 684
Rockville, Maryland

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch, Seismology Division

Subject: Quarterly Progress Report No. 2, Project A-754; Contractor Georgia Tech Research Institute; Order No. 2020-4; Date of Contract - March 13, 1964; Amount of Contract: $39,955; Contract No. CGS-1237(Neg) (Sponsored by Advanced Research Projects Agency); Contract Expiration Date: 12-31-65; Project Scientist: John E. Husted, TR. 6-5976; Covering the Period from April 1 to July 1, 1964; Title of Work: "Studies of the Seismicity of the State of Georgia, Phases I and II."

Gentlemen:

A summary of activities performed during the above mentioned quarter is given below.

1. We obtained from the Seismic Data Laboratory, Alexandria, Virginia, computer listing of distances, azimuths, and predicted arrival times at ATL for teleseismic events reported on U. S. Coast and Geodetic Survey PDE cards for the period June 1, 1963 - March 1, 1964. We also obtained the program that performs these computations.

2. We completed constructing our time recording unit for the recording of local events under Phase II. The first quarry blast was timed June 30, 1964. Based on the assumption that the first arrival was a P_g, we determined a velocity of 5.9 Km. per second over a distance of 42.9 kilometers in crystalline rocks.

3. Seismograms are being read and data collected toward determination of azimuthal sensitivity for the ATL station. Insufficient data has been collected to arrive at any conclusions. It has been found that the travel time charts after Richter and Gutenberg are useable for this area for general application. Again, sufficient data has not been gathered and studied for the determination of residuals.

4. Mr. Husted and Mr. Maynard attended the American Geophysical Union, annual meeting, Washington, D. C., April 24.

FISCAL DATA TO DATE

Contractor expenditures and commitments to date:

	Jan. 1 - June 30	Contract
Expended	$11,638.76	$11,638.76
Encumbered	44.55	44.55
Total	$11,683.31	$11,683.31
Budget	$11,500.00	$39,955.00
Free Balance	(— $183.31)	$28,271.69

Technical-Man-Year effort for first six months of two-year contract is 26.16 per cent.

Estimated Funds to Complete Work: $28,271.69.

Respectfully submitted,

John E. Husted, Head
Minerals Engineering Group
Project Director

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Copies: (4) to Addressee
(6) to Director, Advanced Research Projects Agency,
Department of Defense

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

October 21, 1964

Area Code: 404
Telephone: 873-4211
Ext. 618

Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington Science Center 684
Rockville, Maryland

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch, Seismology Division

Subject: Quarterly Progress Report No. 3, Project A-754; Contractor Georgia Tech Research Institute; Order No. 2020-4; Date of Contract - March 13, 1964; Amount of Contract: $39,955; Contract No. CGS-1237(Neg) (Sponsored by Advanced Research Projects Agency); Contract Expiration Date: 12-31-65; Project Scientist: John E. Husted, 873-4211, Ext. 618; Covering the Period from April 1 to July 1, 1964; Title of Work: "Studies of the Seismicity of the State of Georgia, Phases I and II."

Gentlemen:

A summary of activities is as follows:

1. A combination of circumstances has prevented timing of quarry blast during this quarter.

(a) Weather: several quarries had their time for blasting advanced because of rapidly approaching thunderstorms and consequently the blast was shot before we could get to the quarry and record the time. Background noise level due to hurricanes also prevented other recording.

(b) SALMON preparation for and standby alerts on Salmon: As you are aware Salmon has been postponed on an almost day-to-day basis. This has effectively prevented scheduling timing of quarry blast work during the latter part of September.

(c) The U. S. Coast and Geodetic Survey had their service crew in for two weeks in August, during which time no recording could be done.

2. Personnel Changes: Mr. Layfayette Maynard left August 31 to start work on a doctrate in geophysics at the University of Hawaii under George Woollard. Dr. Ernest Kaarsberg, Ph.D. in geophysics, joined our staff September 7. We also added John Wilbanks, a senior electronics technician on September 1.

3. SALMON is to be monitored.

4. Our telephone has changed to 873-4211, Ext. 618 or 619 (Area Code 404). From 9:30 p.m. to 7:30 a.m. weekdays and from 12:30 p.m. Saturday to 7:30 Monday our office phone is 873-6326.

Work has continued on teleseismic events.

FISCAL DATA TO DATE

	July 1, 1964 - June 30, 1965	Contract
Expended	$ 4,611.55	$16,250.31
Encumbered	7.60	7.60
Total	$ 4,619.15	$16,257.91
Budget	20,059.00	16,250.31
Free Balance	15,439.85	23,697.09

Technical-Man-Year effort for first 9 months of two-year contract is 38.62 per cent of that proposed.

Estimated funds to complete work: $23,697.09.

Respectfully submitted,

John E. Husted, Head
Minerals Engineering Group
Project Director

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Copies: (4) to Addressee
(6) to Director, Advanced Research Project Agency, Department of Defense

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

January 25, 1965

Area Code: 404
Telephone: 873-4211
Ext. 618

Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington Science Center 684
Rockville, Maryland 20852

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch, Seismology Division

Subject: Quarterly Progress Report No. 4, Project A-754
Contractor Georgia Tech Research Institute; Order No. 2020-4; Date of Contract - March 13, 1964; Amount of Contract: $39,955; Contract No. CGS-1237 (Neg) (Sponsored by Advanced Research Projects Agency); Contract Expiration Date: 12-31-65; Project Scientist: John E. Husted, 873-4211, ext. 618; Covering the period from October 1, 1964, through December 31, 1964.
Title of Work: "Studies of the Seismicity of the State of Georgia, Phases I and II."

Gentlemen:

A summary of activities is as follows:

1. Georgia Institute of Technology (Georgia Tech) recorded the "SALMON" event on three separate seismic units. First was the six instrument standard station. Second was a 16 vertical geophone (15 cps) array using a truck mounted exploration unit. The recording was on photographic paper. The 3,000 foot cable was oriented parallel to propagation with the center approximately one-half mile from the standard station. Timing was from the "Blackjack" broadcast. Third was a two vertical geophone (1 cps) array with visual recording using a Texas Instrument strip recorder. The geophones were in close proximity of the two end geophones of the exploration truck. Timing was from WWV signal. The strip recorder is the one secured under this contract for timing quarry blast. Records from the standard station were airmailed to Washington and records from the other instruments were sent to the Project Coordinator for SALMON.

Work on items two and three above were without cost to the Contractor and were completed as part of Georgia Tech's effort to increase its capability in geophysics.

It should be pointed out that SALMON was postponed on a day to day and hour to hour basis for a month. This kept Georgia Tech personnel from effectively doing anything else, and hence, not only kept other contract work from being done, but also created a backlog of work that carried essentially to the end of the quarter.

2. Quarry blast timing was not accomplished during this period because of the aforementioned events and inclement weather. Recording is projected during the coming quarter with one blast already recorded, details of which will be included in Quarterly Report No. 5.

3. Time residuals for teleseismic events, taken from USC&GS "Earthquake Data Report," have been plotted as a function of distance. In addition, such local events as could be measured have also been plotted. Data are insufficient to warrant presentation at this time, but details are included in the forthcoming Semi-annual Technical Report No. 2.

FISCAL DATA TO DATE

	July 1, 1964 - December 31, 1964	Contract
Expended	$ 5,871.52	$17,510.28
Encumbered	0.80	0.80
Total	$ 5,872.32	$17,511.08
Budget	$20,059.00	$39,955.00
Free Balance	$14,186.68	$22,443.92

Technical-Man-Year effort for this first year of a two-year contract is 41.97 percent of that proposed. Estimated funds to complete work are $22,443.92.

Respectfully submitted,

John E. Husted, Head
Minerals Engineering Group
Project Scientist

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Copies (4) to addressee
(6) to Director, Advanced Research Project Agency,
Department of Defense

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

April 9, 1965

Area Code: 404
Telephone: 873-4211
Ext. 618

Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington Science Center 684
Rockville, Maryland 20852

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch
Seismology Division

Subject: Quarterly Progress Report No. 5, Project A-754, Contractor Georgia Tech Research Institute; Order No. 2020-4; Date of Contract March 13, 1964; Amount of Contract: $39,955; Contract No. CGS-1237 (Neg) (Sponsored by Advanced Research Projects Agency); Contract Expiration Date: 12-31-65: Project Scientist: John E. Husted, 873-4211, Ext. 618: Covering the period from January 1, 1965, through March 31, 1965; Title of work: "Studies of the Seismicity of the State of Georgia, Phases I and II."

Gentlemen:

A summary of activities is as follows:

1. Quarry blasts were timed at locations near the towns of Douglasville, Gainesville, Norcross, Red Oak, and Stockbridge, Georgia. The Gainesville blast, at a distance of 96 km., was not well recorded by ATL and the record written by the Norcross blast, at 63 km., was marginal. In order to obtain more reliable arrival times, a portable seismograph with better high-frequency response than the Standard Station equipment was used.

   It is anticipated that registration of the more distant quarry blasts will be improved when the background noise level diminishes enough to allow the magnification to be raised from 50,000 to 100,000.

   A seismic system suitable for long refraction studies which is being acquired for use in the cooperative East Coast Onshore-Offshore Experiment this summer may also be used in cases of difficult reception.

   In addition to the timing system described in previous reports, a 16 channel seismic exploration unit is being used for quarry blast timing and determination of granitic near surface velocities.

The staff of the Cumberland Plateau Seismic Observatory has been helpful in furnishing data to aid in the location of more distant quarries whose blasts are registered here.

2. Work is progressing on the determination of regional magnitude corrections for this station.

FISCAL DATA TO DATE

	July 1, 1964 - March 31, 1965	Contract
Expended	$10,427.11	$22,065.87
Encumbered	$ 416.30	$ 416.30
Total	$10,843.41	$22,482.17
Budget	$20,059.00	$39,955.00
Free Balance	$ 9,215.59	$17,872.83

Technical-Man-Year effort for the first quarter of second year of two-year contract is 22.51 percent; contract to date is 55.03 percent. Estimated funds to complete work are $17,872.83.

Respectfully submitted,

John E. Husted, Head
Minerals Engineering Group
Project Scientist

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Copies (4) to addressee
(6) to Director, Advanced Research Project Agency, Department of Defense

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

September 28, 1965

Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington Science Center 684
Rockville, Maryland 20852

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch
Seismology Division

Subject: Quarterly Progress Report No. 6, Project A-754, Contractor: Georgia Tech Research Institute; Order No. 2020-4; Date of Contract: March 13, 1964; Amount of Contract: $39,955; Contract No. CGS-1237 (Neg) (Sponsored by Advanced Research Projects Agency); Contract Expiration Date: 12-31-65; Project Scientist: John E. Husted, 873-4211, Ext 618; Covering the period from April 1, 1965, through June 30, 1965; Title of Work: "Studies of the Seismicity of the State of Georgia, Phases I and II".

Gentlemen:

A summary of activities is as follows:

1. Quarry blasts were timed at Gray, Georgia, at a distance of 98 km., and at Beverly, South Carolina, a distance of 217 km. from ATL. For these shots, a portable seismograph was set up on the ATL piers. The system consisted of one Hall Sears HS 10-1 vertical geophone driving a broad band amplifier through a transformer with frequency response down to 1 hz. The output of the amplifier was fed to a magnetic tape recorder. Records were obtained from both events, but, unfortunately, a train was passing the ATL observatory during the Gray shot so the record shows little but the first arrival.

The record from Beverly, South Carolina, shows a first arrival with frequency about 5 hz. followed in about one second by 10 hz arrival. It is not yet clear whether or not the first arrival is p_n.

On both of these events, the first arrivals on the standard station records are not clear.

2. A considerable part of the work done this quarter has been done in preparation for the East Coast Onshore-Offshore Seismic Experiment.

Georgia Tech will field two units - a modified seismic exploration truck and a broad band, three component unit recording on magnetic tape. The broad band unit will be entirely R-C coupled so the somewhat uncertain response characteristics of low frequency transformer will not have to be considered.

FISCAL DATA TO DATE

	April 1, 1965 - June 30, 1965	Contract
Expended	$15,693.79	$27,332.55
Encumbered	$ 0.30	$ 0.30
Total	$15,694.09	$27,332.85
Budget	$20,059.00	$39.955.00
Free Balance	$ 4,364.91	$12,622.15

Technical-Man-Effort for second half of two-year contract is 43.76 percent; contract to date is 68.41 percent. Estimated funds to complete contract before renewal is $12,622.15.

Respectfully submitted,

John E. Husted, Head
Minerals Engineering Group
Project Scientist

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Copies: (12) Addressee
(6) Director, Advanced Research Projects Agency, Department of Defense

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

October 14, 1965

Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington Science Center 684
Rockville, Maryland 20852

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch
Seismology Division

Subject: Quarterly Progress Report No. 7, Project A-754, Contractor Georgia Tech Research Institute; Order No. 2020-4; Date of Contract: March 13, 1964; Amount of Contract: $39,955; Contract No. CGS-1237(Neg) (Sponsored by Advance Research Projects Agency); Contract Expiration Date: 12-31-65; Project Scientist: John E. Husted, 873-4211, Ext 618; Covering the period from July 1, 1965, through September 30, 1965; Title of Work: "Studies of the Seismicity of the State of Georgia, Phases I and II".

Gentlemen:

A summary of activities is as follows:

1. On the twenty-third of July an explosion was fired near Gainesville, Georgia, by the U. S. Geological Survey as part of their crustal studies program. This shot was recorded at two field locations in addition to the ATL observatory. The distances were 110 km., 130 km., and 85 km., for the observatory and the field units respectively.

2. On the sixteenth of September the explosion of a munitions ship was recorded by the broad-band equipment operating on the ATL piers. The tape recorder malfunctioned before the record was played back so it is not certain that a record was obtained.

3. Work was resumed on a digital computer program to compute epicentral distances, azimuths, and predicted travel times from PDE data. This program is essentially the same as one written at the Seismic Data Laboratory in Alexandria, Virginia, by B. J. Greer. This program will enable rapid determination of magnitude residuals from seismogram readings already taken. It will then be possible to increase several-fold the density of data points on the magnitude residual map submitted in the most recent semi-annual report. The original contract is near completion; a new proposal is in process for an extension.

FISCAL DATA TO DATE

July 1, 1965 - September 30, 1965

		Contract
Expended	$4,881.79	$32,214.34
Encumbered	$ .00	$ .00
Total	$4,881.79	$32,214.34
Budget	$6,311.07	$39,955.00
Free Balance	$1,429.28	$ 7,740.66

Respectively submitted,

John E. Husted, Head
Minerals Engineering Group
Project Scientist

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Copies: (12) Addressee
(6) Director, Advanced Research Projects Agency, Department of Defense

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

July 30, 1964

Area Code: 404
Telephone: TR. 6-5976

Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington Science Center 684
Rockville, Maryland

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch, Seismology Division

Subject: Semiannual Technical Report No. 1, Project A-754; Contractor Georgia Tech Research Institute; Order No. 2020-4; Date of Contract - March 13, 1964; Amount of Contract: $39,955; Contract No. CGS-1237(Neg) (Sponsored by Advanced Research Projects Agency); Contract Expiration Date: 12-31-65; Project Scientist: John E. Husted, TR. 6-5976; Covering the Period from January 1 to July 1, 1964; Title of Work: "Studies of the Seismicity of the State of Georgia, Phases I and II."

Gentlemen:

Attached hereto please find a description of technical work performed during the above mentioned six months. Also attached are copies of records obtained under Phase II.

Respectfully submitted,

John E. Husted, Head
Minerals Engineering Group
Project Director

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division
Enclosures

Copies: (4) to Addressee
(6) to Director, Advanced Research Projects Agency, Department of Defense

SEMIANNUAL TECHNICAL REPORT NO. 1

"STUDIES OF THE SEISMICITY OF THE STATE OF GEORGIA, PHASES I AND II"

Synopsis

The identification and reporting of P-phases of both teleseismic and local events has been an immediate and prime undertaking of the project to date. Preliminary work on computer programming was discontinued after receipt of a computer program from Seismic Data Laboratory. Phase II equipment was purchased and assembled for recording the time of local events and one local event was so recorded.

TECHNICAL WORK UNDER PHASE I

The highest priority activity has been the identifying and reporting of P-phases to the Epicenter Location section of the Seismology Division of the U. S. Coast and Geodetic Survey. While a detailed statistical analysis has not yet been made, the C&GS Earthquake Data Reports ("Friday Data Sheets") indicate that at least 60% of the events reported have residuals less than one second, with another 20% having residuals between one and two seconds. Positive residuals outweigh negative somewhat, but the distribution around zero seems fairly good.

Since the elastic properties of the area are not very well known, there is a definite temptation to compare residuals with such other seismic stations as are located nearby. Residuals seem near those of other stations of equal or greater magnification -- for instance, when CPO and ATL report the same event, residuals are usually consistent -- and definitely smaller than those for stations with less magnification.

In addition to identification of teleseismic events, considerable effort has been made to identify locally originating events, particularly persistently recurring ones. These events, in the great majority of cases, are the result of blasting in quarrying, mining, construction, and road building activities, all of which are being very actively carried on in the area.

Most of the blasts can be recognized quite readily since they have small P components, very much larger S and L components, very short S-P intervals, and almost invariably occur in the top half (daytime) of the gram. Furthermore, they diminish in number on Saturdays and almost disappear on Sundays and holidays. Certain ones, either quite small or distant, can be distinguished from teleseismic phases by the envelope shape and the dispersion

shown. By comparison of the three components the Love and Rayleigh waves can be identified, often giving classical examples of theoretically predicted wave groups and forms.

Two persistent exceptions to the rule of "no night or weekend blasting" are frequently repeated records of events having S-P intervals of roughly one-half minute and one minute, respectively. The events having S-P of roughly 30 seconds seem from the components to be roughly due west putting them in the vicinity of Birmingham, Alabama. Underground mining could explain the fact that night does not stop blasting. The other set of events having S-P of about 60 seconds has about equal magnitudes of all three components, indicating probable origins at azimuths of either 45°, 225°, or 315° from the seismograph. Eliminating 135° as being in the Atlantic Ocean, off of the Florida coast, these azimuth and deltas correspond respectively to northwestern North Carolina, the Mobile Bay area, or western Tennessee. So far it has been impossible to choose one of these azimuths since the components are always quite small.

Blasting reports from all those quarrying operators who will cooperate are still being collected in order to identify and tabulate the characteristic waves received as well as determine local travel times.

With the acquisition of a globe and charts, data indicating sensitivity of the station with respect to azimuths is accumulating. Immediately apparent is the great sensitivity of the station to events in Alaska and the Aleutian Islands, in the Carribean and Central America, and in South America. The station is rather insensitive to areas of the continental United States west of the Rocky Mountains, however, most Mexican events are recorded quite well.

Four definitely local seismic events have been recorded and located this year. Two of them, the Lookout Mountain earthquake (Feb. 18) and the Macon earthquake (March 12), were located by USC&GS Seismology Division, and the separately determined locations were in good agreement. A third earthquake (March 7), very small and located in western South Carolina near Clark Hill Reservoir, has not been corroborated by Epicenter Location but was recorded by Blacksburg. A fourth possible small earthquake, reported by the Columbia, S. C. station, was also recorded. The Macon (actually Sinclair Lake) earthquake and the events near Clark Hill Reservoir are to be used along with gravimetric and magnetic data collected on another project, to try to trace a postulated fault across middle Georgia. This data will be useful in Phase III of the project.

The Georgia Tech computer system uses ALGOL and a preliminary program was devised for the determination of azimuth and distance from the Georgia Tech Station. In April contact was made with the Seismic Data Laboratory of Alexandria, Virginia, for comparison of their FORTRAM program with what we were using. As a result of this contact we were sent a complete program, as well as azimuths calculated from PDE cards for our station. The Seismic Data Laboratory program included more accurate ellipticity corrections and in consequence produced better predictions. A comparison of azimuths and distances determined by the Georgia Tech originated program and the Seismic Data program reflected only very small differences. In view of the fact that the azimuth data was being calculated by the Seismic Data Laboratory, we felt that we could more profitably use our time for other work and avoid duplication. It was, therefore, decided to discontinue work on the Georgia Tech program and use the Seismic Data Laboratory's information.

TECHNICAL WORK UNDER PHASE II

Crustal Velocity Determination for Local Events

Equipment has been purchased and assembled to allow timing of quarry explosions to within about .02 seconds. This is done as follows:

The radio time signal from WWV is received on a Specific Products, Inc., receiver model WVTR. The audio output from this receiver is fed to a time pulse amplifier which amplifies the time "tick" and closes a relay at the beginning of each second. The relay remains closed for about 400 milliseconds (msec.) and is used to control the marker pen of a Texas Instruments two-channel "Oscillo-riter" strip chart recorder. This recorder has a rise time of 0.8 msec. and a maximum sensitivity of 1 volt/cm. The equipment listed above is all mounted in a cabinet rack.

On 30 June, 1964 this equipment was used to time a quarry blast at the Rock Chapel plant of Consolidated Quarries, Lithonia, Georgia.

The shot studied was a wall shot on the north wall of the east quarry. Du Pont explosives in the following kind and amounts were shot: ANFO: 20,100 lbs.; TOVAL: 16,050 lbs.; HI-CAP: 1900 lbs.: PELLETOL: 1500 lbs.; and HI-VELOCITY 60%: 1150 lbs. There were 136 holes on 9 X 12 feet spacing averaging 58 feet in depth. The shot was fired in delays: 25, 50, 75, 100, 125, 150, 175, 200, 225, and 250 msec. The 250 msec. were the corner holes.

The time of the explosion was detected by two methods:

A. A pair of wires shorted at the end, was led through the top primer of one of the face holes (25 msec. delay). This pair of wires was connected to the input of the amplifier feeding the right channel of the recorder. The high side of the input was connected to a high resistance 20 volt source. When the wire was broken by the explosion, the 20 volts was applied to the

amplifier input, deflecting the pen.

B. Four pairs of "Shell" geophones (about 30 cps resonant frequency) were connected in series, in proper phase, and connected to the input of the left channel of the recorder, which was set at 1 volt/cm sensitivity. The geophones were placed on the top of the quarry wall about 200 feet back from the face.

The marker pen of the recorder was used for time control as described previously.

Radio reception was good and the time signals were recorded well. Both methods of detection produced clean breaks, however, the shot break leads shorted about 5 seconds after the explosion commenced. The signal from the geophones was much stronger than expected and the recorder pen was driven violently off scale.

Xerox copies of both the strip recording and SP - Z seismogram from ATL are attached.

Computation of Distance and Travel Times from Rock Chapel Quarry to Std. Sta. ATL.

The position of quarry as determined from USGS topographic map 7.5 minute series, Snellville Quadrangle, is 33°45.26' N, 84°04.26 W. The position of ATL is:

33°26' N, 84°20.25 W.

ℓ is $33°45.26 - 33°26.00 = 19.26'$

Dlo is $84°20.25 - 84°04.26 = 15.99'$

Cos $33°35'$ = .83308

Dlo Cosθ = 13.32

$D = \sqrt{(19.26)^2 + (13.32^2)}$

$= \sqrt{370.9476 + 177.44224} = \sqrt{548.3700}$

= 23.417 Nautical Miles

= 23.417Nm X 1.85325 $(Km/_{Nm})$ =

43.397 Km

The time that the blast commenced was 18:54'08.32 EST 30 June 1964.

The time of the first p arrival was 18:54:15.90

$\Delta T = \begin{cases} 18:54:15.90 \\ 18:54:08.32 \end{cases}$

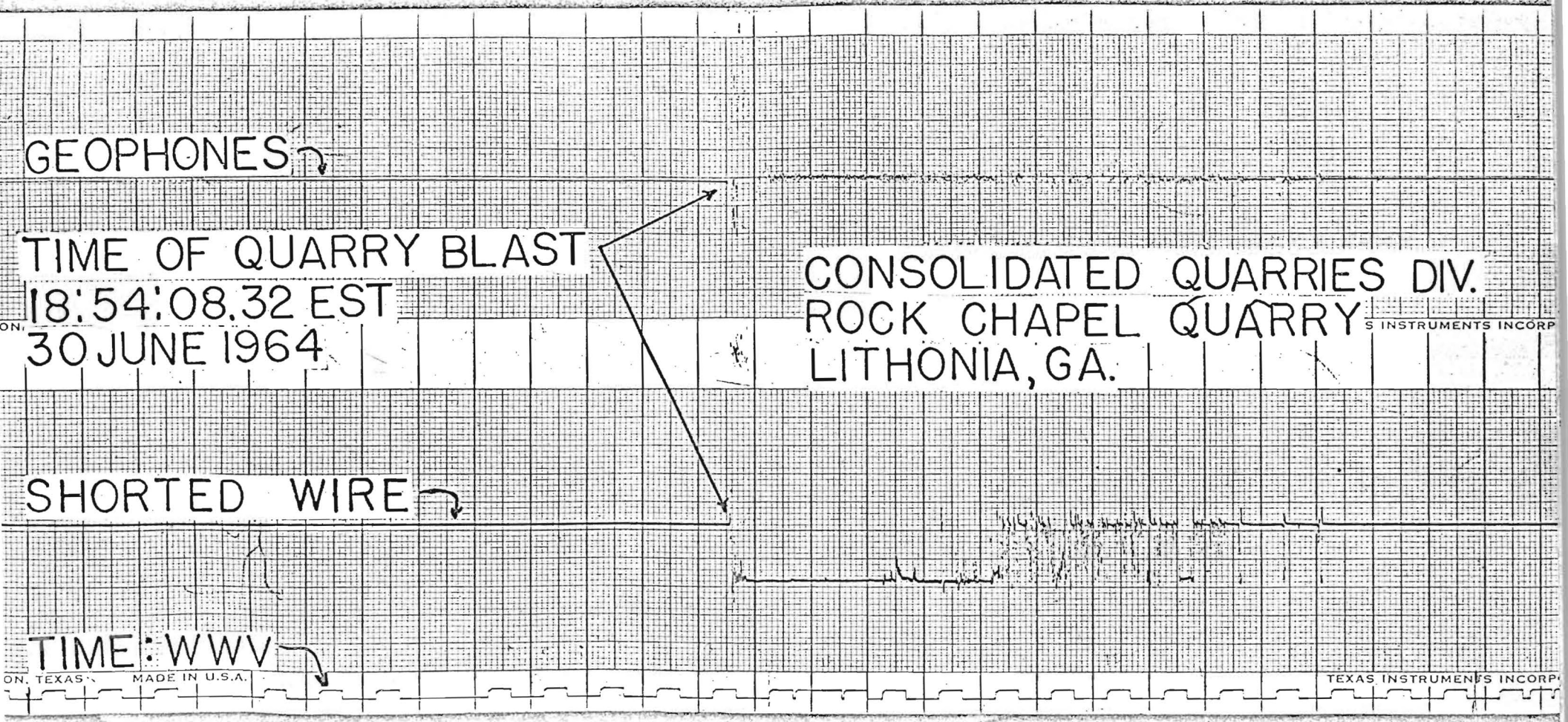
07.27 sec.

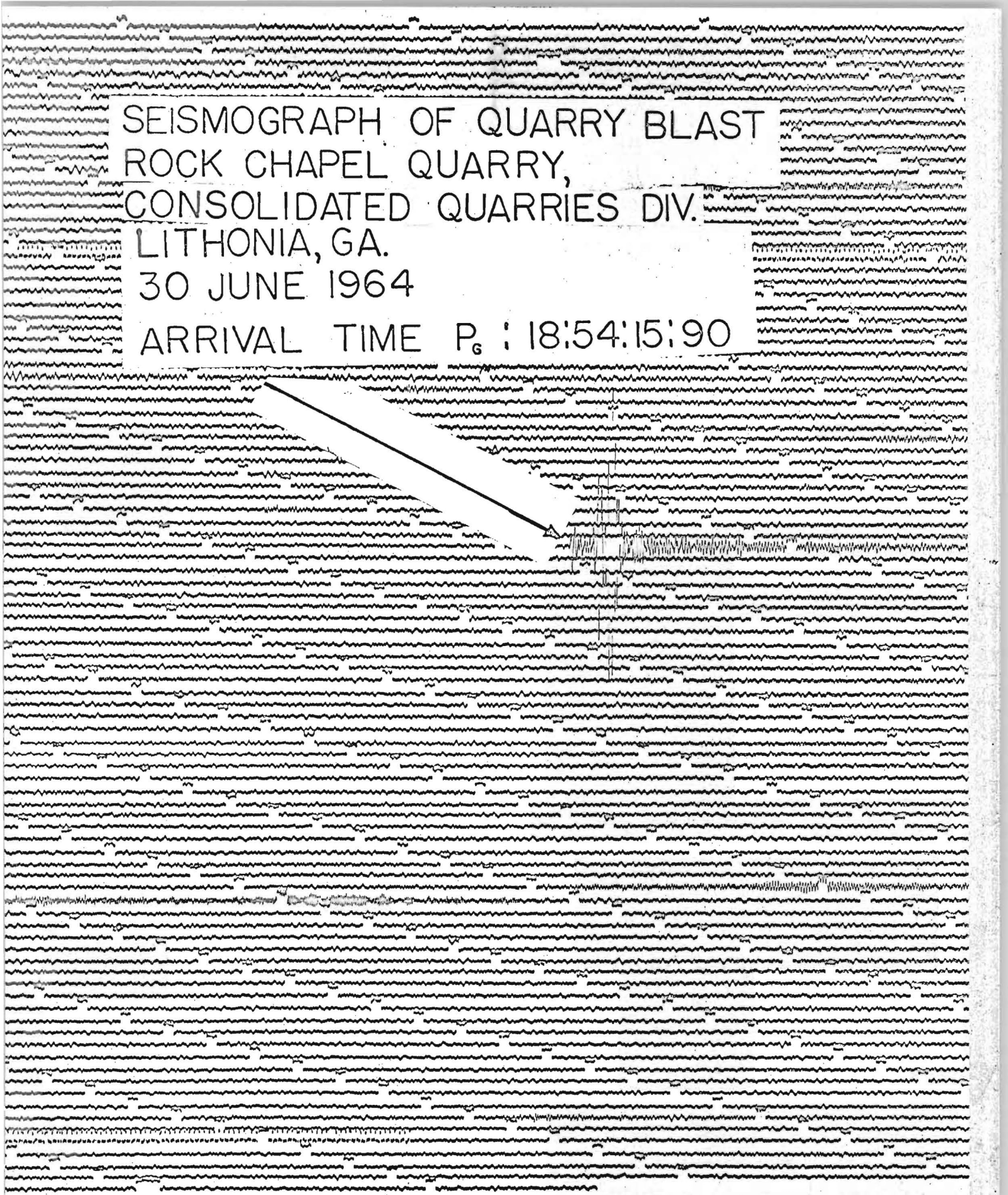
If we make the assumption that the first arrival is P_g, we arrive at the velocity:

$V_{pg} = \frac{43.397}{7.27}$ 5.97 Km/Sec.

Plans

It is planned that the equipment described above will be continued to be used in timing local events. A series of quarries lie nearly in line from the western Fall Line to the northeast part of the state, on trend with regional structure. Another series of quarries may be found in line from the Fall Line near the middle of Georgia and extending northwestward into the Paleozoic sediments near Chattanooga. This line is essentially normal to regional structure. Both lines cross the Georgia Tech Seismological Observatory. By using these series of quarries it is hoped that velocities and profiles may be obtained that will indicate some knowledge of the crust and, possibly, Upper Mantle in Georgia.


GEOPHONES
TIME OF QUARRY BLAST
18:54:08.32 EST
30 JUNE 1964
CONSOLIDATED QUARRIES DIV.
ROCK CHAPEL QUARRY
LITHONIA, GA.
SHORTED WIRE
TIME: WWV
MADE IN U.S.A.
TEXAS INSTRUMENTS INCORP


SEISMOGRAPH OF QUARRY BLAST
ROCK CHAPEL QUARRY,
CONSOLIDATED QUARRIES DIV.
LITHONIA, GA.
30 JUNE 1964
ARRIVAL TIME P_G : 18:54:15:90

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

January 29, 1965

Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington Science Center 684
Rockville, Maryland 20852

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch, Seismology Division

Subject: Semi-annual Technical Report No. 2, Project A-754; Contractor Georgia Tech Research Institute; Order No. 2020-4; Date of Contract - March 13, 1964; Amount of Contract: $39,955; Contract No. CGS-1237(Neg) (Sponsored by Advanced Research Projects Agency); Contract Expiration Date: 12-31-65; Project Scientist: John E. Husted, 873-4211, Ext. 618-619; Covering the Period from July 1 to December 31, 1964; Title of Work: "Studies of the Seismicity of the State of Georgia, Phases I and II."

Gentlemen:

Attached hereto please find a description of technical work performed during the period July 1 to December 31, 1964.

As covered in Quarterly Reports 3 and 4, inclement weather, change of personnel and "Salmon" slowed the rate of effort. The next six months are anticipated as being more productive.

Respectfully submitted,

John E. Husted, Head
Minerals Engineering Group
Project Scientist

Approved:

Frederick Bellinger, Chief
Chemical Sciences & Materials Division

Enclosures

Copies: (4) to Addressee
(6) to Director, Advanced Research Projects Agency, Department of Defense

SEMI-ANNUAL TECHNICAL REPORT NO. 2

"STUDIES OF THE SEISMICITY OF THE STATE OF GEORGIA,

PHASES I AND II"

Synopsis

Work has been confined to analysis of seismograms for both local and teleseismic events, with emphasis on teleseismic events.

Technical Work, Phases I and II

The program of analysis of seismograms, aside from routine reading and reporting of arrivals, has two primary objectives: the examination of residuals from the Jeffreys-Bullen travel time tables to determine whether or not there are any corrections which could be applied to make the tables more accurately reflect travel time observed at this station; and the computation of regional magnitude corrections for this station.

The time residuals for all of the ATL readings published to date in the semi-weekly USC&GS "Earthquake Data Report" have been plotted as a function of distance. These several hundred data, in the main, indicate average residuals of a second or less. Since this involves a quantity which is of the same order of magnitude as the uncertainty in the epicenter determination, it is not yet deemed possible to determine time corrections. As more data accumulate, they will be studied as functions of distance, azimuth and depth of focus. Quarry blast travel times and the "Salmon" data indicate that, for near disturbances, negative residuals occur; e.g., -2.6 seconds for "Salmon" at 544 km and -.8 for a quarry blast at 43 km.

Regional corrections (m_r) to magnitude computations are being obtained in the following manner:

$$m_r = m_{ATL} - m_b$$

where m_{ATL} is the body magnitude computed from the ATL seismograms and m_b is the body magnitude from the USC&GS PDE computations. In the Aleutian area $m_r = -.5$. In the western U.S., $m_r = +.5$. In some areas, the standard deviation is fairly small, being 0.22 for a group of five earthquakes in 1963 near Andreanof Island in the Aleutians.

In the future it is planned to compute regional corrections for M_s, the magnitude from surface waves.

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

September 7, 1965

Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington Science Center 684
Rockville, Maryland 20852

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch, Seismology Division

Subject: Semi-annual Technical Report No. 3, Project A-754; Contractor - Georgia Tech Research Institute; Order No. 2020-4; Date of Contract - March 13, 1964; Amount of Contract: $39,955; Contract No. CGS-1237(neg) (Sponsored by Advanced Research Projects Agency); Contract Expiration Date: 12-31-65; Project Scientist, John E. Husted, 873-4211, Ext. 618,619; Covering the Period from January 1 to June 30, 1965; Title of Work: "Studies of the Seismicity of the State of Georgia, Phases I and II".

Gentlemen:

As mentioned in personal conversation, the report attached hereto was delayed as our entire staff was in the field from the period of June 16 to July 20 for recording on the onshore-offshore seismic profile of the East Coast. Prior to entering the field, considerable time was also given to preparation for the project. A proposal requesting a renewal of the current program after the scheduled December 31 termination is in progress.

Respectfully submitted,

John E. Husted, Head
Minerals Engineering Group
Project Scientist

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

Enclosures

Copies to: (12) Addressee
(6) Director, Advanced Research Projects Agency, Department of Defense

SEMI-ANNUAL TECHNICAL REPORT NO. 3

"STUDIES OF THE SEISMICITY OF THE STATE OF GEORGIA,

PHASES I AND II"

Synopsis: Preliminary results are given from earthquake body wave magnitude studies and from local explosion studies.

TECHNICAL WORK UNDER PHASE I

Earthquake Magnitude Studies

The objective of this portion of the program is to examine regional deviations using the depth distance (Q) function of Gutenberg and Richter (1956). The body wave magnitude m_B was defined as

$$m_B = \log_{10} \frac{A}{T} + Q + c$$

where A is the amplitude of the maximum ground motion of the first few cycles of the P phase measured in microns; T is the period of maximum ground motion in seconds; Q is the depth distance correction function; and c is a station ground correction, here assumed to be zero.

Let us define m_{ATL} as the body wave magnitude of an earthquake determined from the ATL observatory readings alone. When this m_{ATL} is subtracted from the average body wave magnitude published in the Coast and Geodetic Survey epicenter cards, a magnitude residual, m_r, is obtained which will serve as a measure of amplitude deviations from the expected value. This m_r is the logarithm of the ratio of the expected value of A/T to the locally observed A/T. Thus, a positive value of m_r will indicate higher than usual attenuation of the waves, and similarly, a negative value of m_r indicates lower than usual attenuation. If m_r is added to the locally determined m_{ATL}, the published magnitude m_{pub} is again obtained. Thus, m_r serves as a magnitude correction. There is considerable scatter in the values of m_r determined for earthquakes in a

region so it becomes necessary to use the mean of the m_r values from several (n) earthquakes.

We then define an average m_r for a region as

$$\overline{m}_r = \frac{\sum_{1}^{n} m_{i\ pub} - m_{i\ ATL}}{n}$$

This $\overline{m}_r$ was computed for earthquakes occurring in each "square" bounded by meridians and parallels five degrees apart. In this case, n is the number of shocks per "square".

The earthquakes were distributed as follows:

Earthquakes per square	Number of squares
1	52
2	11
3	7
4	8
6	2
8	2
10	1
32	1

The $\overline{m}_r$ values for these squares were plotted on a map and the map was contoured by hand. Regional trends appeared to be present. See Fig. 1.

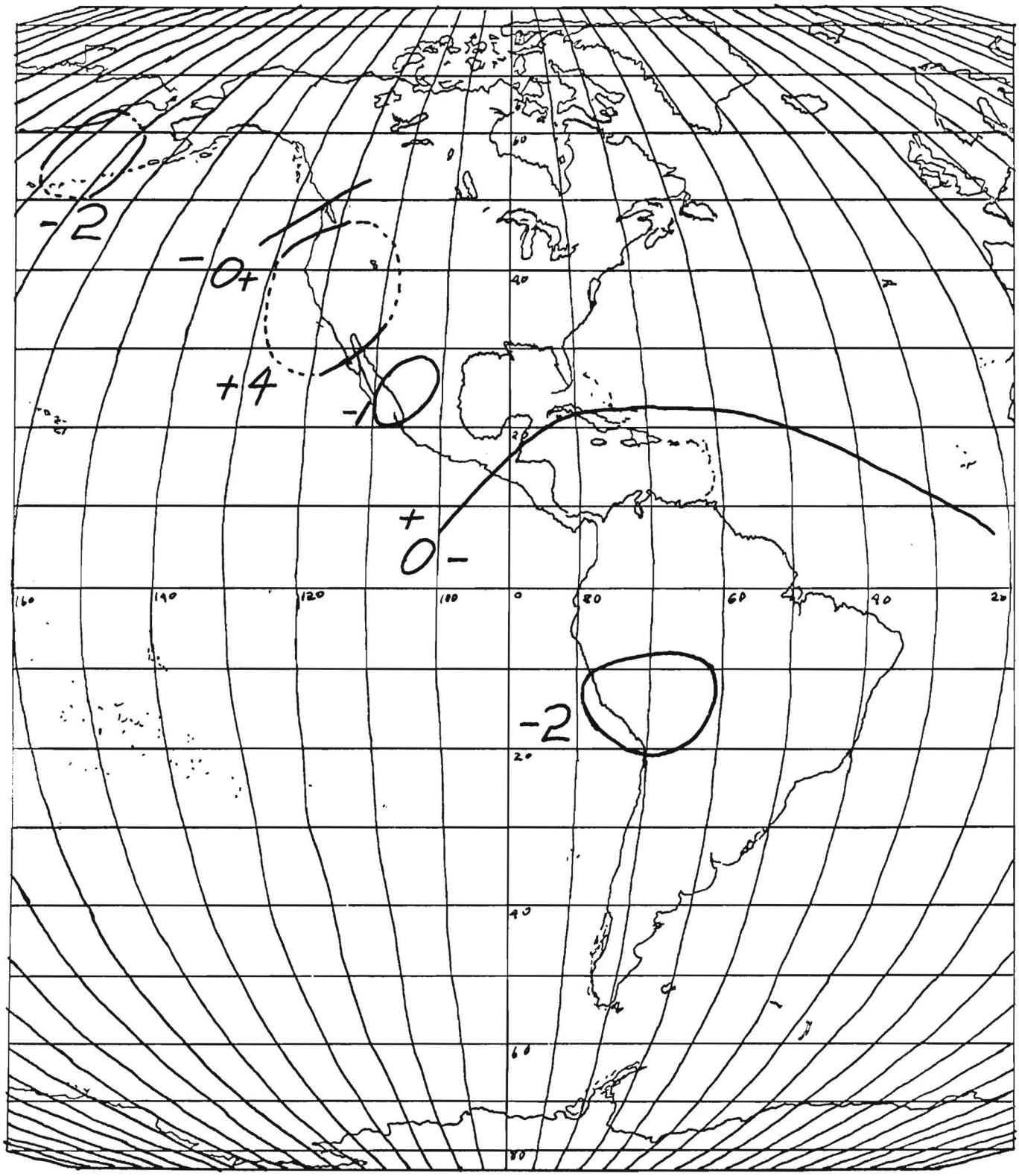


Fig. 1. Regional magnitudes $\overline{m}_r$ in units of 0.1 magnitude

The question then arises whether these differences are statistically significant; and if they are, whether the deviations are due to path anomalies, source anomalies, or are due to the local inapplicability of the "Q" function of Gutenberg and Richter.

The standard deviations (s) were computed in each case where the number of shocks per square exceeded five. These are as follows:

Square	Number of Earthquakes	$\bar{m}_r$	s
50N 170E	32	-0.24	0.30
50N 175E	7	+0.04	0.21
50N 175W	7	-0.26	0.42
45N 150E	7	-0.36	0.28
15N 90W	6	-0.05	0.43
15N 95W	8	+0.04	0.30
10N 85W	6	-0.39	0.36
10N 90W	10	-0.05	0.37
5N 80W	7	-0.47	0.35
20S 65W	8	+0.11	0.25

It is apparent that the values of $\bar{m}_r$ are of the same order of magnitude as the standard deviations and it becomes essential to perform an objective statistical test of significance. The map (Fig. 1.) shows that the west coast of the U. S. has the largest deviation and, conveniently, there are seismically active areas off the west coasts of Central and South America at similar distances, thus allowing a comparison in which the effects of distance are removed. Accordingly, two groups of earthquakes were selected; one group of eight with epicenters near the west coast of

the U. S., north of 30°N. Lat.; and one group of fifty-two with epicenters south of 30°N. Lat., all with distances between 18 and 36°. For the West Coast group, $\bar{m}_{r_1}$ = +0.48 with standard deviations s_1 = 0.37. For the southwest control group, $\bar{m}_{r_2}$ = -0.13 with s_2 = 0.40. Inspection of the histograms (Fig. 2) of the distribution of the value of $\bar{m}_r$ shows that the values contributing to $\bar{m}_{r_2}$ have nearly normal distribution and those contributing to $\bar{m}_{r_1}$ are as good as can be expected with so few data and such a large standard deviation.

Following Fisher (1925) we make use of the "t" statistic in testing whether two samples, whose means and variances are known, are drawn from the same population.

$$t = \frac{(\bar{m}_{r_1} - \bar{m}_{r_2}) \sqrt{n_1 + n_2 - 2}}{\sqrt{n_1 s_1^2 + n_2 s_2^2}} \sqrt{\frac{n_1 n_2}{n_1 + n_2}} \qquad (2)$$

where n_1 and n_2 are the number of samples used in the computation of $\bar{m}_{r_1}$ and $\bar{m}_{r_2}$ respectively.

Substituting into (2) we obtain

$$t = 4.2$$

which indicates that the difference is highly significant. It further follows that the difference $(\bar{m}_{r_1} - \bar{m}_{r_2})$ could be as small as 0.33 and still be significant at the ninety-five percent confidence level.

The level of significance derived from the variances of the data can be somewhat misleading in that it cannot reflect the systematic inaccuracies

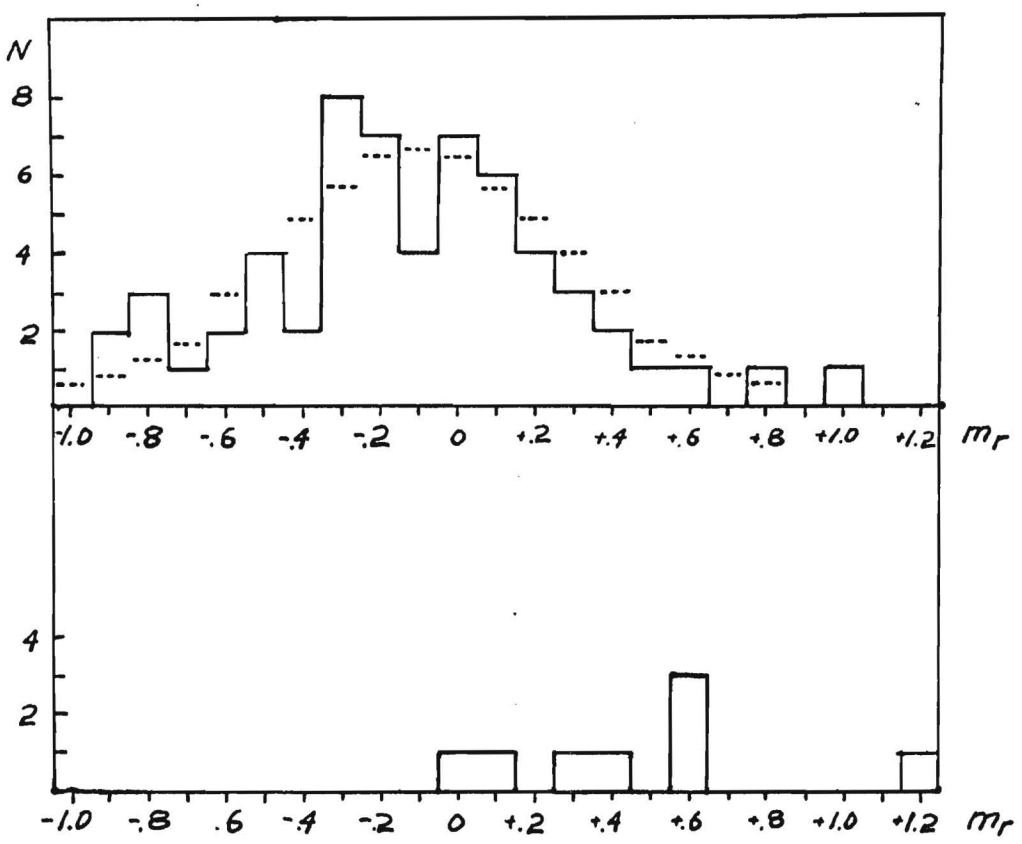


Fig. 2. Top-Distribution of $\overline{m}_r$ in control region. Dotted lines indicate normal distribution.

Bottom-Distribution of $\overline{m}_r$ in the West Coast region.

in the published magnitudes due to the effect of the irregular distribution of stations and systematic deviations from azimuthal symmetry at the source. So in this case the statistics tell only the minimum uncertainty. It should be recalled that an earlier computation using five earthquakes in an area much smaller than those used here gave $\bar{m}_r = -0.5$ with $s = 0.22$. With more data, the five degree square containing this area showed a much smaller $\bar{m}_r$ with a standard deviation not much greater.

TECHNICAL WORK UNDER PHASE II

Near Earthquake Magnitudes

The Q function originally published by Gutenberg and Richter has been modified and extended by the Coast and Geodetic Survey for use in their epicenter and magnitude program (U.S.C.G.S., 1963). The values of the Q function were reduced by 0.3 to allow use of double amplitudes and the function used with the Z component of the P phase (shallow focus) was extended to distances down to 2°.

An earthquake with $m_B = 4.4$ occurred at 0.9° from ATL on 12 March 1964. The depth-from the Coast and Geodetic Survey data-was 40 km. For the P_n phase, ATL registered T = 0.3 seconds, A = -0.087 microns, so

$$\log \frac{A}{T} = \log 0.29 = -0.54$$

T is the period of the first few cycles of P energy and A is the amplitude. From the definition of m_B,

$$m_B = \log \frac{A}{T} + Q$$

We can substitute into this equation the published m_B and the observed value of $\log \frac{A}{T}$ and obtain a Q. This gives

$$Q = 4.94 \text{ for } \Delta = 0.9°$$

When the Gutenberg and Richter Q value is extended downward using an inverse cube distance factor, a value of 3.9 is obtained. This indicates that the P arrival here had a $\frac{A}{T}$ value of roughly one tenth of that predicted by a simple inverse cube extension of the Q factor.

Explosion Studies

The objectives of these studies are to derive local travel time data and information on local crustal structure from records of explosions.

Thus far, records at distances of less than 220 km. have been obtained from seven commercial explosions and from the explosion at Gainesville, Georgia, fired by the U. S. G. S. as part of their crustal studies program. The U. S. G. S. Gainesville shot on 23 July 1965, was recorded by portable equipment at two sites fifteen kilometers from the observatory toward and away from the shotpoint. The locations of these explosions are shown in Fig. 3.

The arrivals from these explosions indicate P velocities of 6.0 km/sec. and S velocities averaging 3.6 km/sec. These velocities indicate a Poissons ratio of 0.21.

The arrivals have also been assembled without regard to azimuth and treated as an unreversed seismic profile. The reduced travel times of arrivals at ATL are shown in Fig. 4. The numbers beneath the arrivals correspond to the numbers by the explosion locations in Fig. 3. It can be seen that the first arrivals from #5, 8, and 7, at the distances of 62.9, 110, and 217 km. to the northeast respectively, exhibit negative time residuals of close to a second when plotted against 6.0 km/sec. The first arrivals from #5 and 8 are not strong, so there is a strong possibility of error. The doubtful arrivals were not used in the calculation of velocities. In addition, the fact that the residuals are close to one second raises the suspicion of a timing error. It is planned to repeat these timings with the broad band equipment mentioned later.

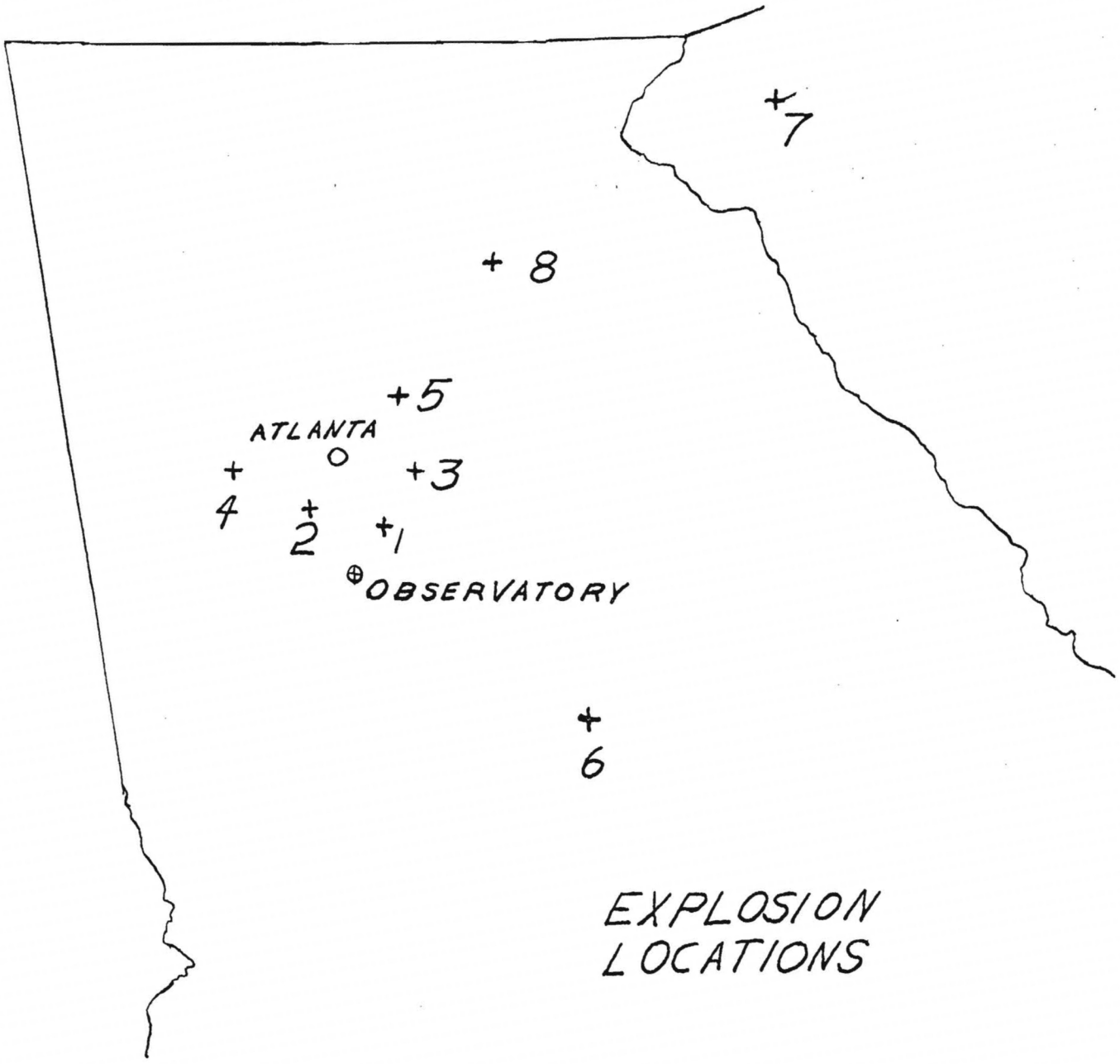


Fig. 3. Locations of explosions recorded at ATL.

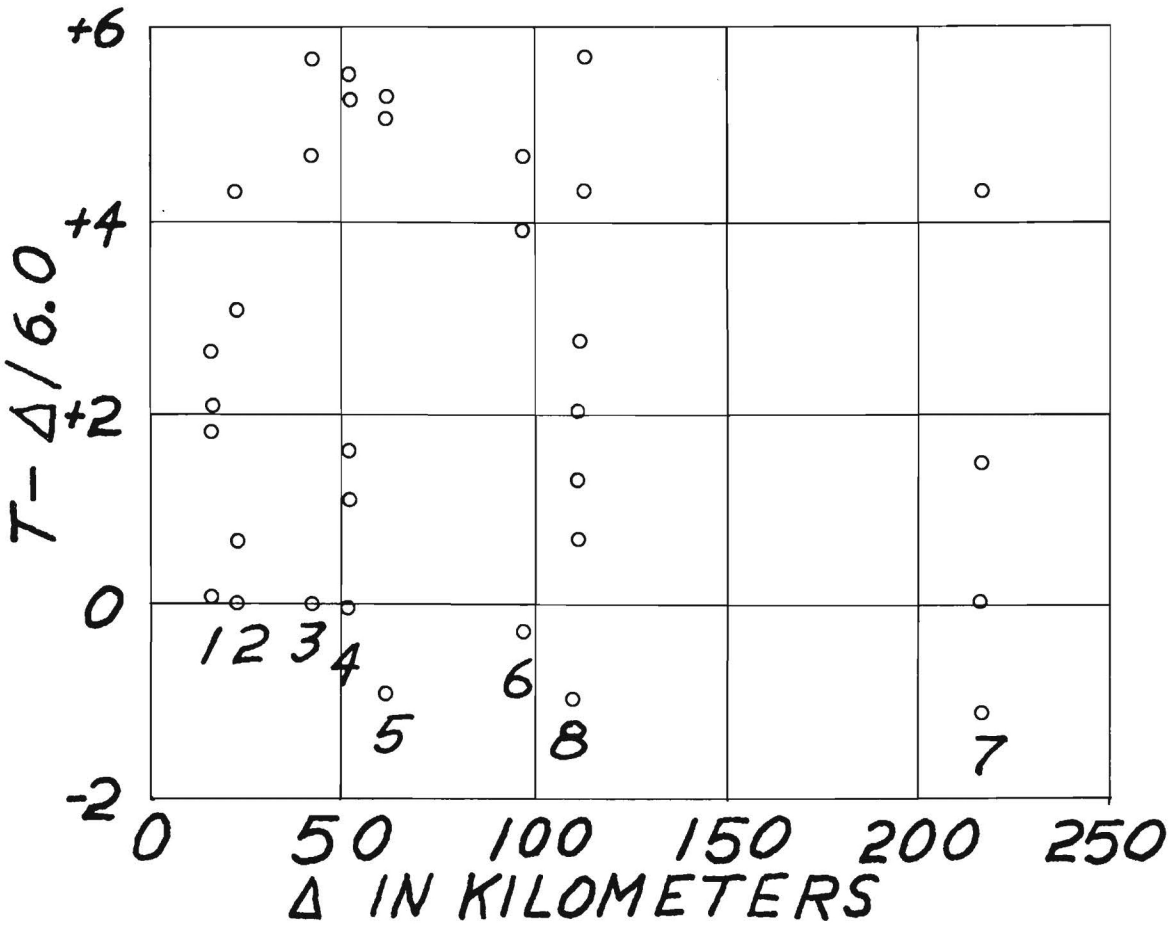


Fig. 4. Reduced travel times of explosion arrivals recorded at ATL.

Collection of additional data may allow fitting of a simple crustal structure model. At present the density of data points is low enough to allow the fitting of models with crustal thickness ranging from 31 km. to 47 km.

The short period standard station system is a less than perfect instrument for this type of work. Its best response is not in the five- to ten- cps range where the maximum energy from the blasts is found and the compressed time scale (1 mm/sec.) makes precise timing difficult.

Explosions #7 and 6 were recorded on magnetic tape with broad band equipment (1-60 cps) and produced records with signal to noise ratios much higher than those of the standard station records. Unfortunately, shot #6 took place while a railway train was passing the recording site.

The larger offshore shots, fired as part of the East Coast Onshore-Offshore seismic experiment, were received by ATL, but with low energy. These shots were at distances of the order of 500 km. Travel time and distances have not been computed yet because shot times and locations are not available at present.

The observation of these explosions was made possible by the generous cooperation of the Stockbridge Stone Division of Vulcan Materials Company, Consolidated Quarries Division of Georgia Marble Company, The Campbell Limestone Company, Weston and Brooker Quarries, and the Crustal Studies Branch of the U. S. Geological Survey.

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GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

January 20, 1966

Office of Physical Sciences
U. S. Coast and Geodetic Survey
Washington Science Center 684
Rockville, Maryland 20852

Attention: Dr. S. T. Algermissen, Chief
Data Analysis Branch
Seismology Division

Subject: Semi-annual Technical Report No. 4, Project A-754; Contractor Georgia Tech Research Institute; Order No. 2020-4; Date of Contract - March 13, 1964; Amount of Contract - $39,955; Contract No. CGS-1237(Neg)(Sponsored by Advanced Research Projects Agency): Contract Expiration Date: 12-31-65; Project Scientist - John E. Husted, 873-4211, Ext. 618,619; Covering the Period from July 1, 1965, to December 31, 1965; Title of Work: "Studies of the Seismicity of the State of Georgia, Phases I and II."

Gentlemen:

The short period surface wave dispersion data given in this report promise to be of considerable use in exploring the crustal structure of this area. Dr. James Dorman of Lamont Observatory has reviewed this work and made several suggestions regarding the analysis. He is furnishing computer programs for the generation of dispersion curves from models. This will assist considerably in the interpretation.

Respectfully submitted,

John E. Husted, Head
Minerals Engineering Group
Project Scientist

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

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Copies to: (12) Addressee
(6) Director, Advanced Research Projects Agency, Department of Defense

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia

SEMI-ANNUAL TECHNICAL REPORT NO. 4

"STUDIES OF THE SEISMICITY OF THE STATE OF GEORGIA, PHASES I AND II"

By

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Synopsis: Explosion studies indicate crustal velocities of 6.2 and 3.6 km/sec for compressional and shear waves, respectively. Preliminary results of short period surface wave studies are given.

CRUSTAL STUDIES

As was reported in the latest semi-annual report, arrivals from eight artificial explosions indicate granitic velocities of 6.2 km/sec and 3.6 km/sec for P_g and S_g velocities respectively. These data are shown in figure 1. Three additional explosions, the "Salmon" nuclear event in Mississippi at about 500 km and the "Chase III" and "Chase IV" chemical explosions off the coast of Virginia at about 1000 km were used to determine P_n, the upper mantle velocity of about 8.2 km/sec. These data are shown in figure 2.

In order to make a first approximation to the crustal structure, a model consisting of one layer of constant thickness over a half space was considered. The data shown in figure 2 require a crustal thickness of 40.7 km for this model. The assumption of constant depth to the mantle is not altogether implausible in this case since most of the shotpoints are on a line sub-parallel to the Appalachian chain.

Observations of Surface Waves

McEvilly and Stauder (1) have used stripmine blasts to investigate shallow structure in Illinois and Missouri by studying Rayleigh wave velocities. The quarries in and around Georgia commonly fire shots in the walls of the quarries to break crystalline rock. These are highly assymetric events and the blasts radiate horizontally polarized shear and Love waves as well as compressional and Rayleigh waves. Thus, it is possible to use the Love and Rayleigh wave dispersion to help clarify the sometimes ambiguous results of refraction seismology.

At a distance of over 200 km, differences in group velocity are sufficient to separate two major wave trains. From examination of the particle motion these were identified as Love and Rayleigh waves and from the range of the

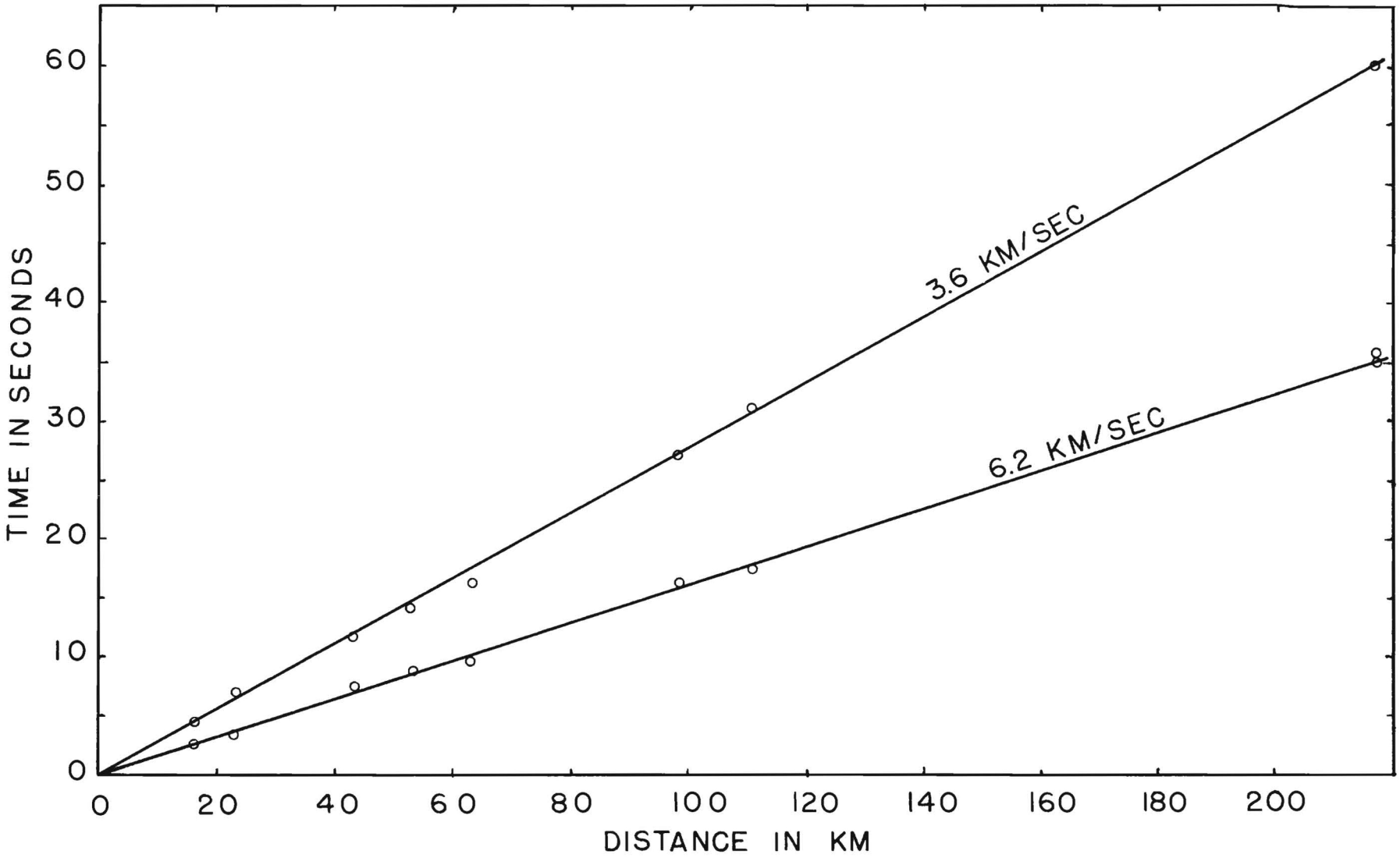

Figure 1. P_g and S_g wave travel times from ATL observatory

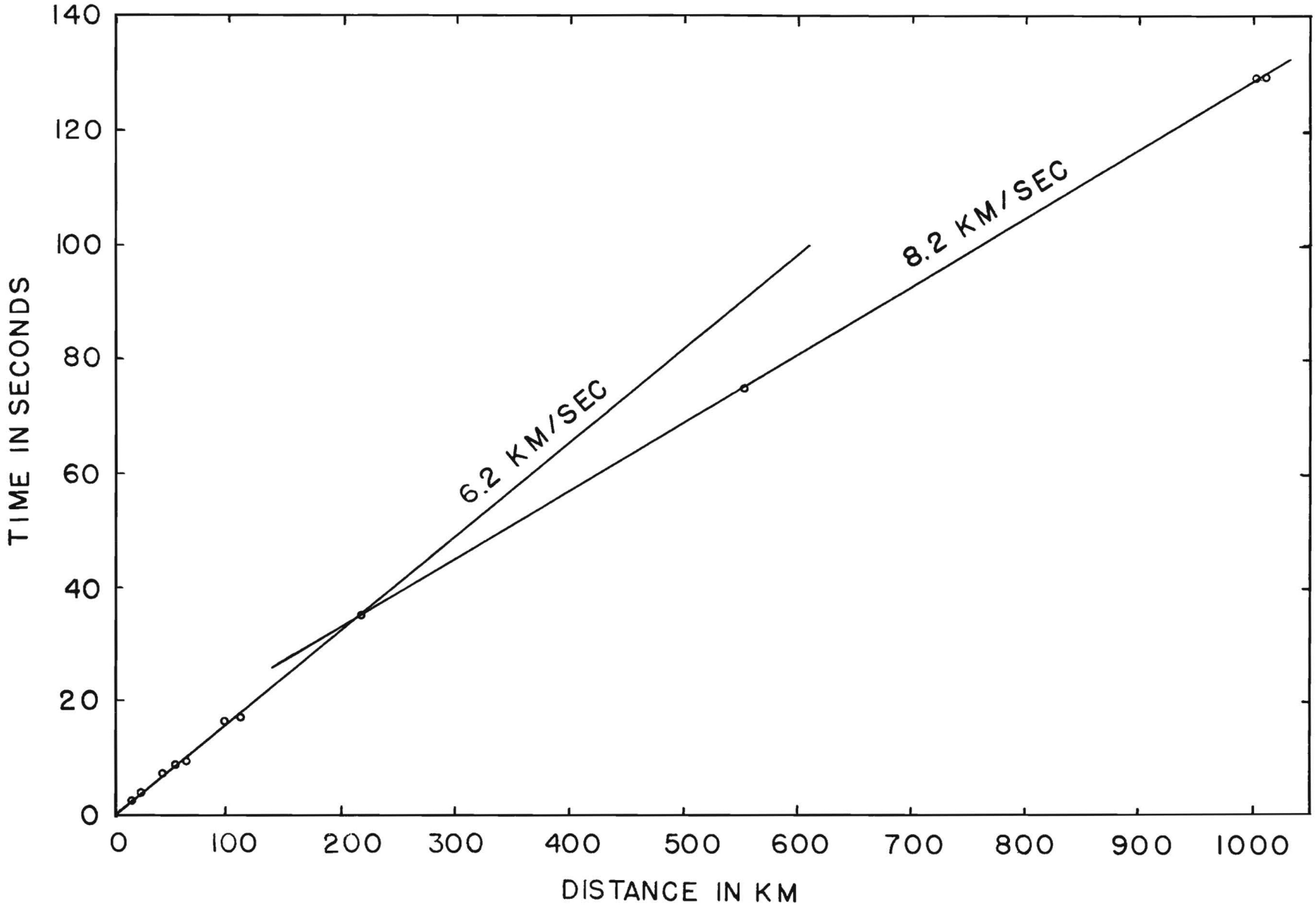

Figure 2. P-wave travel times from ATL observatory.

group velocities, it appears that these are the fundamental modes. The group velocities were obtained by the usual manual method of plotting the times of the peaks and zero crossings. The slope of the resulting curve gives the period and can then be graphed against arrival time or group velocity. This curve was not smoothed prior to computation of the derivative and, as a result, the scatter of the data was increased. The source of some of the scatter is in that the short periods of the waves are difficult to measure at one mm/sec paper speed. If the curve is smoothed, advantage is taken of the fact that measuring one period a little short will necessarily cause another to be too long. It is planned to fit a polynomial to the data points using a least square adjustment and then take the derivative analytically instead of using the slopes of lines connecting adjacent points.

It is probable that the short period end of the Love wave train was slightly contaminated by another phase since there appeared to be an S-shaped "bend" superposed on the group velocity curve, making the function appear to be multiple valued in period. This was noted primarily on one of the horizontal records. Both horizontal records were used to obtain the Love wave data while only the vertical was used for the Rayleigh.

In the computation of the group velocities, the effect of instrumental phase shift was not considered.

The Rayleigh group velocity curve was compared with that computed by Mooney and Bolt (2) for a single layer of sediment over a basement. The thickness of the layer was adjusted to 0.18 km so that the velocities matched at one second period. The fit is not good.

One Love wave dispersion curve was computed for a single layer of alluvium over a half space. The thickness of this layer which provided the

observed velocity at one second period was 0.71 km. The fit is not significantly better than that obtained in the Rayleigh case.

The physical properties of the models used are listed in table 1.

TABLE 1

	Rayleigh	Love
Compressional wave velocity in layer	3.05 km/sec	1.9 km/sec
Shear wave velocity in layer	1.52 km/sec	1.1 km/sec
Compressional wave velocity in half space	5.85 km/sec	6.0 km/sec
Shear wave velocity in half space	3.50 km/sec	3.6 km/sec
Density of layer	2.4	1.9
Density of half space	2.67	2.67
Thickness of layer	0.18 km	0.71 km

The dispersion curves from these two models are shown in figure 3 along with Rayleigh and Love velocities over a path northeast from Atlanta. The path is composed of granitic rock overlain by superficial sediments and weathering products. The properties of the Love wave model were chosen to correspond as nearly as possible to the observed properties of the area. With layers this thin, however, the size of the topographic features is the same order of magnitude as the layer thickness and can be expected to have a significant effect. The topographic irregularities would be expected to have the strongest effect on the waves of shortest periods, and no doubt, act as scattering centers so that little short period energy (< 0.5 sec) is received.

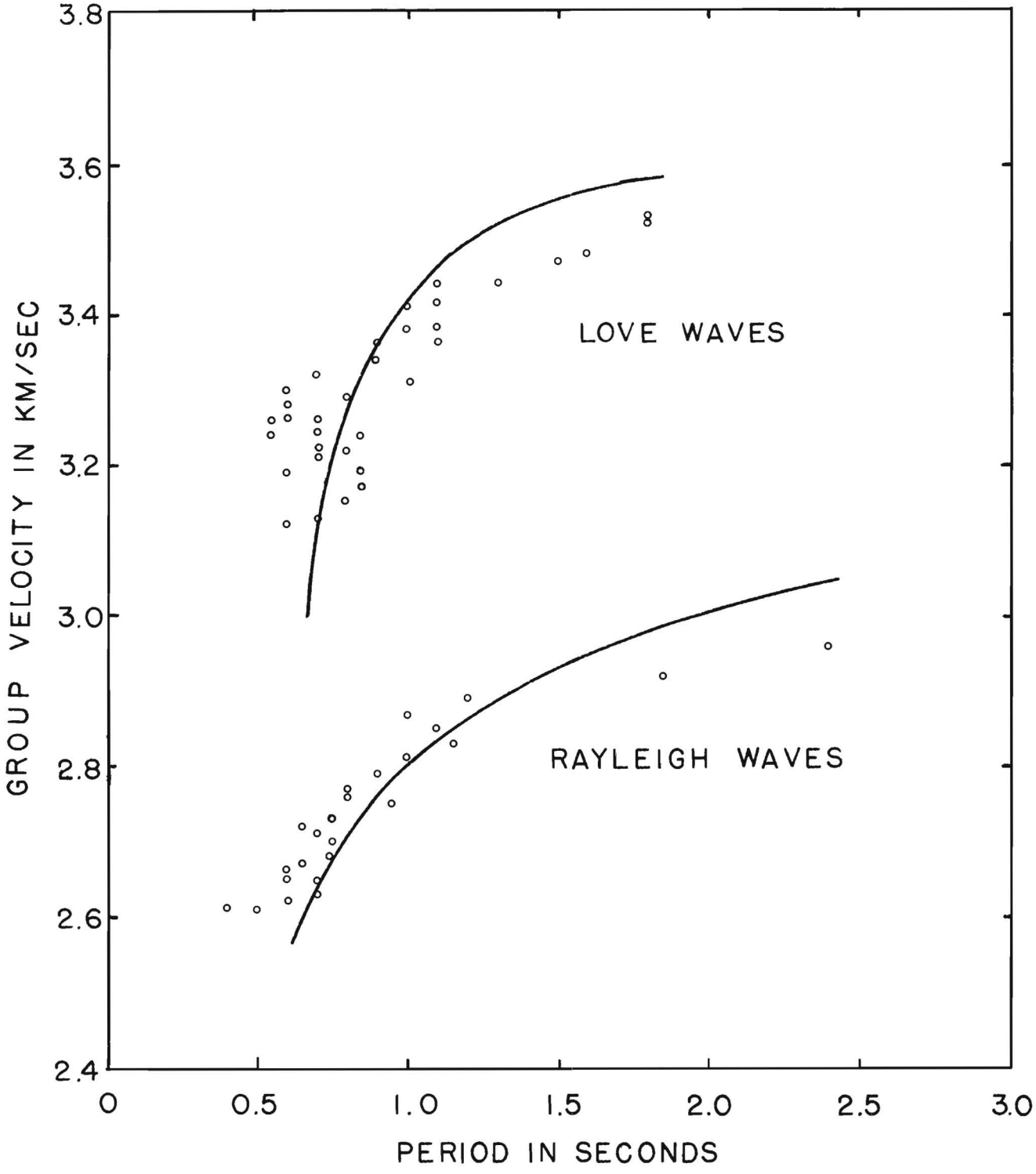

Figure 3. Short period dispersion curve for a path Northeast from ATL observatory.

The two models whose dispersion curves almost fit the data are not consistent with each other and one is not consistent with the seismic refraction data. It has not yet been possible to create a model which satisfied the available data because of the computational problems involved in the inversion of surface wave data.

This approach is promising, however, since the more constraints which can be placed on the model, the more likelihood there is that the model faithfully reflects the actual geology.

SEISMICITY STUDIES

In order to make an estimate of local seismic activity, a search was made of the seismograms written at the ATL observatory. In addition to the one event reported in the U. S. C. G. Epicenter cards, seven events have been classified as probable earthquakes. The most serious problem was distinguishing the earthquakes from the numerous quarry blasts taking place in the area. Three criteria were used for this purpose:

1. Size - The largest blasts normally fired by local quarries are sixty thousand pounds of explosives and produce records similar to those from earthquakes of local magnitude 2.0 to 2.5. In the study of local seismicity the local magnitude (M_L) scale was used since surface waves are well registered from small earthquakes while the body phases have short, difficult to measure periods. In addition depth distance tables for body phases are not available for short distances. It has not yet been demonstrated that the depth-distance function derived by Gutenberg and Richter for southern California is applicable to this region but it appears to be all that is available.

2. Location - If disturbances occurred in an area where it was known that there were no mining operations, they were classified as earthquakes.

3. Time of day - Most quarries blast at noon or in the afternoon after quitting time. This allows them to load during daylight and causes no interruption of other operations. For reasons of safety, blasting is not done at night. Hence, a large event occurring

in the middle of the night is almost certainly of natural origin.

Where the first arrivals were impulsive, it was possible to obtain an azimuth by using the directions of first motion and thus obtain a position. The azimuthal accuracy of this method is, of course, low.

The salient data on these events are listed in table 2. Where no position is given, it was not possible to determine an azimuth.

TABLE 2

Date	Time(T)	Latitude	Longitude	Local Magnitude	Remarks
8 Oct. 1963	06 01 43.4	34° 12'N	82° 44'W	2.8	
7 Mar. 1964	18 03 00.1	34° 06'N	82° 50'W	3.2	
13 Mar. 1964	01 20 18.2	33° 33'N	83° 25'W	3.2	M_b=4.4 from C.G.S.
20 Apr. 1964	19 04 45.0	--	--	3.6	
7 Apr. 1965	07 41 10.2	33° 45'N	82° 32'W	2.7	
22 July 1965	23 55 33.3	--	--	2.9	
8 Nov. 1965	12 58 01.0	34° 12'N	84° 37'W	2.5	
8 Nov. 1965	13 04 11.5	34° 12'N	84° 37'W	3.0	

It appears that during the past few years, local activity has been confined to the northern part of Georgia and South Carolina. If time and funds permit, film chips of seismograms written at Columbia, South Carolina, and at McMinnville, Tennessee, will be examined for evidence of the events whose positions are presently unknown.

A graph of magnitude vs. time is given as figure 4. It is interesting that the events appear to be grouped as two sequences of shocks generally increasing in size.

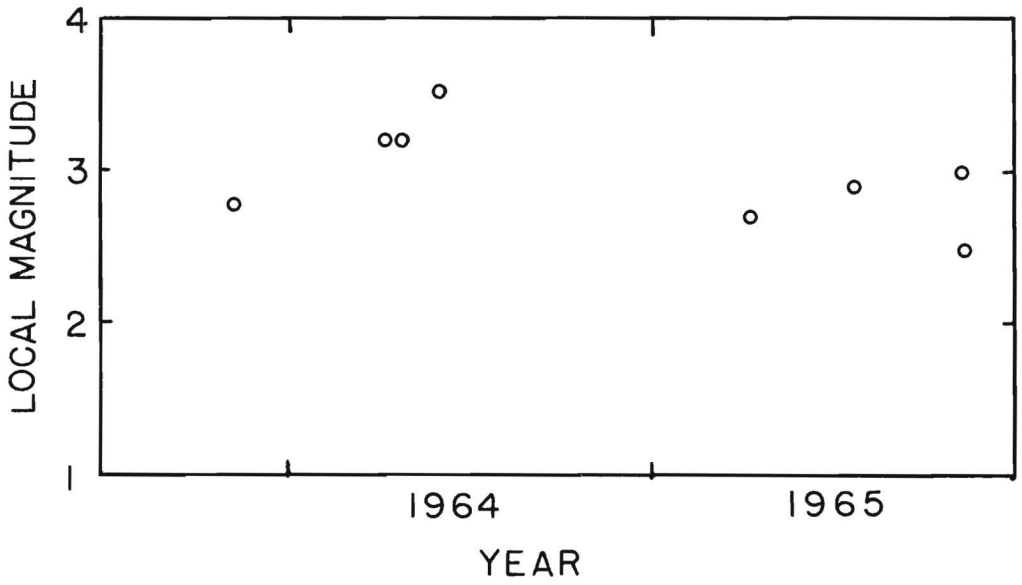

Figure 4. Local earthquake magnitudes as a function of time.

REFERENCES

(1) McEvilly, T. V., and William Stauder, S.J., "Effect of Sedimentary Thickness on Short Period Rayleigh Wave Dispersion," Geophysics Vol XXX, No. 2, 198-203, April 1965.

(2) Mooney, Harold M., and Bruce A. Bolt, "Dispersion Tables for Rayleigh Waves on a Single Surface Layer," VESIAC Special Report 4410-102-X, Institute of Science and Technology, The University of Michigan, Ann Arbor, 1965.

(3) Gutenberg, B., and C. F. Richter, "Earthquake Magnitude, Intensity, and Acceleration," Bulletin of the Seismological Society of America, Vol. 46, 105-145 (1956).